Grain Orientation Mapping of Passivated Aluminum Interconnect Lines with X-ray Micro-Diffraction.

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INTRODUCTION

Electromigration is the physical movements of atoms in metallic interconnect lines passing current at high electron density (typically in the range of 10^5 amp/cm^2). Significant material movement results in voids that consequently lead to breakage and circuit failure in the metal lines. This problem gets more severe as the line dimensions continue to shrink on integrated circuits. In spite of much effort in this field (1,2,3), electromigration is not understood in any depth or detail, but is strongly associated with the physical material properties (stress and strain) within the interconnect material. X-rays have been used to measure these properties in materials on the macro scale - this work describes the start of a program to perform similar measurements on the micro scale and its applicability to the electromigration problem. X-rays are quite well suited to such measurements as they are able to penetrate several microns into matter. This is important as interconnect lines are invariably encased in an insulator such as silicon dioxide (this is known as passivation). X-rays are thus able to probe the buried samples in their natural environment. Sample sizes are typically the grain sizes and are on the micron length scale. With the use of the x-ray micro probe techniques developed at the ALS, sample wires can be studied on a grain by grain basis.

EXPERIMENTAL CONSIDERATIONS

X-ray diffraction usually involves the determination of the x-ray diffraction angle with fixed photon energy. In such a case the sample is rotated through the Bragg condition. This is appropriate for large samples and large x-ray beams where the sphere of confusion of the goniometer (typically several tens of microns) is small compared to the sample interaction volume. When working on the micro scale, we have adopted the alternative approach that fixes the sample position, but still generates x-ray diffraction as the sample can be illuminated with polychromatic radiation from the ALS bend magnet synchrotron source. The sample can be considered to consist of many grains in random orientation. To see diffraction from such random individual grains requires the use of white light. This will generate a Laue pattern that can be used to determine grain orientation. The photon energy and position of the Laue spots will allow determination of the strain within the individual grain. This can also be carried out on a grain by grain basis. The data is intended as input for micro mechanical modeling calculations.

In summary there are two goals of this program to characterize micro crystals

1. grain orientation mapping
2. strain measurements on the separate grains.

This present work describes our progress towards the first goal of grain orientation mapping.

EXPERIMENTAL

Figure 1 shows the experimental setup. The synchrotron source of size typically 300 x 30 μm FWHM (horizontal and vertical) is located some 31m distant from the apparatus. The source is imaged with demagnifications of 300 and 60 respectively by a set of grazing incidence platinum-coated elliptically bent Kirkpatrick-Baez (K-B) focusing mirrors (4). Imaged spot sizes have been measured as 0.8 micron FWHM in size. Photon energy is either white of energy range 6-14 keV or monochromatic generated by inserting a pair of Si(111) channel-cut monochromator crystals into the beam path. A property of the four crystal monochromator is its ability to direct the monochromatic primary beam along the same direction as the white radiation. Thus, the sample can be irradiated with either white or monochromatic radiation. The x-ray probe motion on the sample between white and monochromatic modes has been measured to be less than 0.5-μm. White radiation is required for Laue experiments, which allow for crystal grain orientation determination. Monochromatic radiation is to be used for d-spacing measurements to determine stress/strain determination of single grains in the metal line.

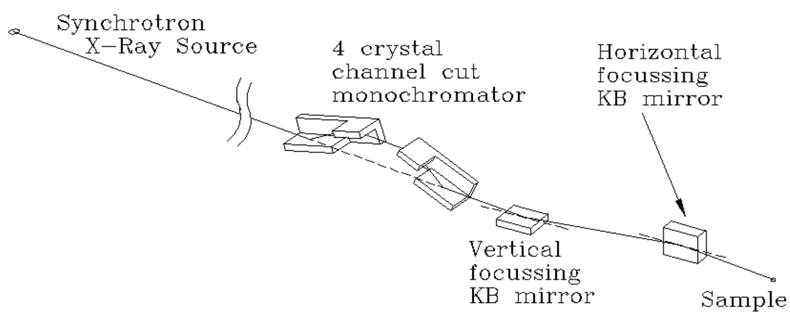

Figure 1 Schematic layout of the K-B mirrors and the four crystal channel-cut monochromator

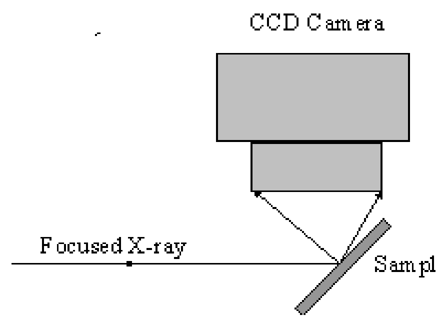

Figure 2 Schematic layout of the arrangement around the sample

The sample was an aluminum line deposited to 0.5-μm thickness and 0.7-μm width on an oxidized silicon substrate. The line was passivated with a plasma-enhanced chemical vapor deposition (PECVD) nitride at 300C to 0.3-μm thickness. Laue patterns were collected using white radiation and a x-ray CCD camera. The exposure time was 1.0 sec and sample-to-CCD distance was 19.63 mm. Fig. 2 shows the arrangement of the sample with the CCD x-ray detector positioned vertically above it. As the x-rays are horizontally polarized, x-ray diffraction is in the vertical plane is the more efficient.

Figures 3A and 3B show the raw data CCD image Laue patterns from the silicon substrate and aluminum line. The 2 images are displaced from each other by 1 micron along the wire length and differences are apparent due to the illumination of different aluminum grains. (The grey areas to the edge of the left and top of the images are defects in the phosphor coating on the CCD and should be ignored.) The dominant spots in the Laue pattern are from the silicon substrate, but when these are digitally subtracted the aluminum Laue pattern is apparent. These aluminum spots are highlighted and indexed in the figures. We have developed an automatic indexing code that can accept as input, the geometric positions of the Laue spots and can output the spot index and grain orientation matrix. The code achieves this by systematically working through the Miller indices and obtaining a best fit to the spot positions for the applicable geometry. The photon energy range (~6-14keV) and aluminum unit cell size allows us to restrict the Miller indices range to 7 and less. The code is able to automatically index patterns for both the single grain Laue case and also for the 2 grain overlapped Laue case. Figures 3A and 3B show that there are 3 grains present in the aluminum line within the 2 micron distance along wire length measured. In both cases there are 2 overlapped grains illuminated by the 0.8 micron x-ray spot, with the grain indicated by "O" being present in both positions. It is clear that the x-ray spot has moved from one side of the "O" grain to the other. This grain has dimensions of about 1 micron and is typical for this sort of system.

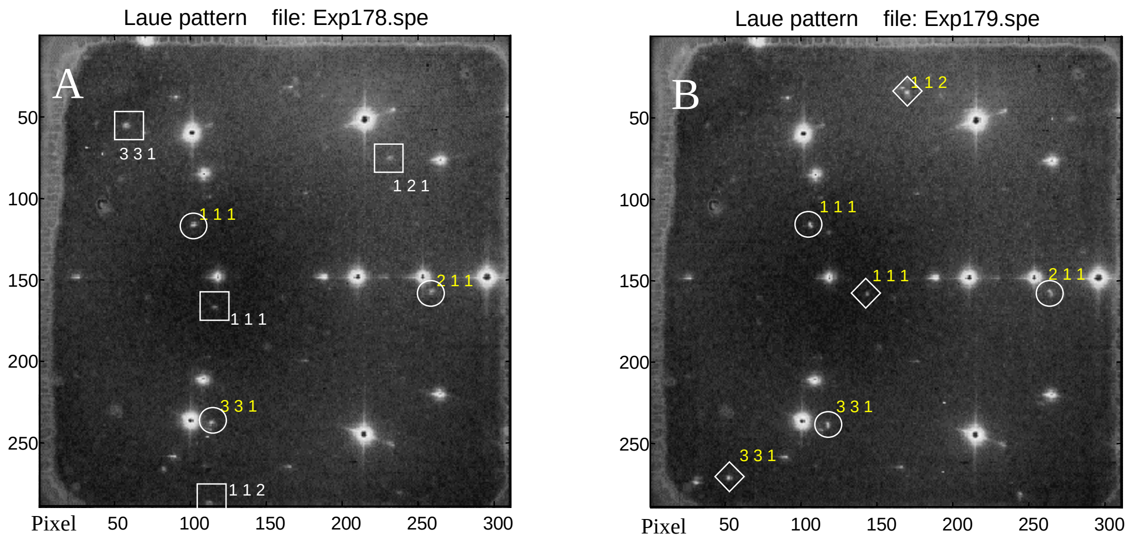

Figure 1. Laue patterns from 0.7 micron wide aluminum wires on a Si (100) substrate. The two images are displaced by 1 micron along the wire length. The intense spots are from the silicon substrate and the weaker spots (highlighted) are from the aluminum grains. Both images contain 2 aluminum grains within the 0.8 micron x-ray spot. The aluminum spots have been automatically indexed and are assigned to separate grains using the square, circle and diamond shape scheme.

CONCLUSION AND FUTURE DEVELOPMENT

We have demonstrated that x-ray micro-diffraction is capable of determining the crystallographic orientation of individual grains in passivated interconnect lines. Orientation mapping has been achieved using automated indexing code that can accept input positions from the aluminum Laue patterns.

Having demonstrated that we can automatically index aluminum lines, we can proceed to the next stage of the project where samples having different processing conditions and various grain orientation maps can be investigated with respect to their electromigration behavior. After this the strain from grain to grain has yet to be measured. A new instrument capable of carrying this out is under construction at this time.

ACKNOWLEDGEMENTS

This work was supported by the Director, Office of Basic Energy Sciences, Materials Sciences Division of the US Department of Energy, under Contract no. DE-AC03-76SF00098. Samples from T. Marieb of Intel Corporation, Santa Clara, CA.

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